Playing with delay: An interactive VR demonstration

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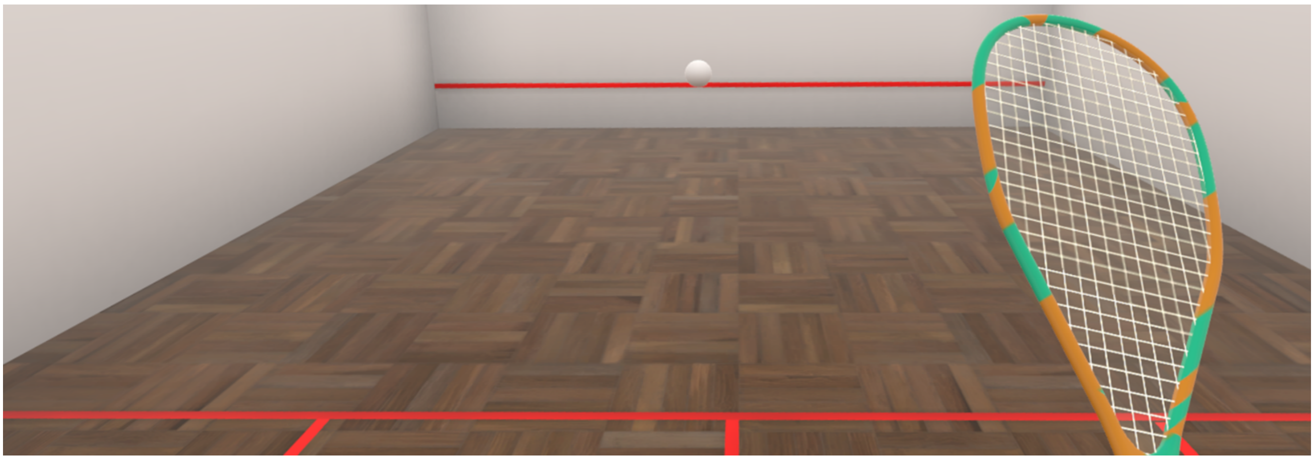

Figure 1: This demo invites participants to play squash in Virtual Reality, and to explore the feel and effect of delay.

ABSTRACT

Virtual reality is now used across a range of applications, from entertainment to clinical purposes. Although the rendered visualisations have better temporal and spatial resolutions than ever, several technological constraints remain – and people still suffer side-effects. With this demonstration, we address the temporal constraints of virtual reality. We invite participants to play a game where they are in charge of the presented delay, facilitating their first-hand experience of the consequences of delay. Furthermore, the demonstration serves as a platform for future explorations into short- and long-term effects of virtual reality constraints.

CCS CONCEPTS

• **Human-centered computing** → **Virtual reality**; *Empirical studies in HCI*.

KEYWORDS

virtual reality, perception, cyber sickness, delay, game

MMVE '19, June 21, 2019, Amherst, MA, USA

ACM ISBN 978-1-4503-6299-3/19/06…$15.00
https://doi.org/10.1145/3304113.3326114

ACM Reference Format:
Kjetil Raaen, Ragnhild Eg, and Ivar Kjellmo. 2019. Playing with delay: An interactive VR demonstration. In *11th International Workshop on Immersive Mixed and Virtual Environment Systems (MMVE '19), June 21, 2019, Amherst, MA, USA.* ACM, New York, NY, USA, 3 pages. https://doi.org/10.1145/3304113.3326114

1 INTRODUCTION AND BACKGROUND

Virtual Reality (from now on *VR*) often refers to the use of stereoscopic head mounted displays (HMD) that cover the entire field of view, where the view tracks the user's head motion. This creates an extremely immersive experience. However, to achieve high quality of experience, the technical requirements are high. The experience also needs to be well designed to avoid discomfort. One important contributor to discomfort is delay. If you turn your head, and the world follows later, the world will feel unstable [1]. There is limited research on exactly what is considered *fast enough* tracking, but one study points to a limit somewhere between 180 ms and 220 ms [1]. (Note that this number is often cited as 50-90 ms. Such a reading ignores the reported inherent latency in the tested system of 122 ms [1].) This contrasts sharply with best practices in the commercial industry, where recommendations are a maximum of 20 ms latency [13], though without citations or apparent empirical data. Resolving this discrepancy will require systematic qualitative and quantitative studies using modern equipment.

This demonstration is the first step towards mapping out the constraints of VR technology, and the subjective consequences of delayed VR interactions. In a game environment that can be used as a test platform for future experiments on VR interactions, we allow participants to experience the perceptual, and possibly physical, consequences of delays in virtual reality. The purpose of this demonstration is to gather feedback on the experience and the methodology, laying the ground for future studies on the effects of delay and possibly other technical factors that may influence the quality of VR experiences.

1.1 Challenges

The industry has come a long way in refining spatial and temporal parameters in VR. Earlier works show that the Oculus Rift allows minimum latencies below 10 ms [15], and the upper bound for HTC Vive is estimated at 22 ms [12]. According to specifications from the manufacturers[1] [13], both the HTC Vive and the Oculus Rift sport 110° field-of-view, 90 Hz refresh rate, and a binocular total of 2160x1200 pixel resolution. Although the industry has come a long way, many solutions are established without transparency. That is, manufacturers have insight about the limitations and requirements of their technology, but this insight is not necessarily available to researchers. Furthermore, some challenges are only moderated, and new ones are discovered along the way. VR set-ups like Oculus Rift and HTC Vive come with high temporal resolutions and minimal delays in motion tracking, which has alleviated associated consequences, but certainly not removed them. The applications that run in VR require additional processing capacities, and the demands increase as applications become more advanced. Furthermore, new interaction modes introduce new challenges, such as tracking limitations in VR controllers, uncovered by a team at Valve software. Apparently, some players exhibit preterhuman-like capabilities in flicking their wrists [14].

Other past challenges that remain unsolved include spatial resolution, flickering, mis-matches between physical and visual motion (vection/optical flow), and mis-representations of depth cues or fields of view [4, 5, 10, 13]. Along with temporal resolution and delays, these are well-studied causes for simulator sickness.

1.2 Side effects and usability

So-called simulator sickness, or cyber sickness, bears many similarities to motion sickness. They are both attributed to the discordance between visual and vestibular signals, and they share symptoms [7], including nausea, disorientation, sweating and oculomotor symptoms such as dizziness, vertigo and visual disturbances [9, 16]. Among these, nausea-related symptoms are typically the ones reported by participants who need to abandon an experiment [2].

Sickness is not the only side effect that follows the technical limitations that still affect VR technology. The virtual experience itself is shaped by restrictions posed by the technology that produces, conveys and renders the VR environment, from graphics, design and layout to sounds and tactile feedback. The somewhat undefined notion of immersion is dependent on the visual world that unfolds in VR [8], but also on other sensory experiences. For instance, real locomotion is a usability issue that researchers are addressing, aiming to tip the immersion scale [18]. Captivating experiences in the real world tend to stimulate more than one sense, implying that multisensory perception is a key to immersion. Yet this key works best with temporal, spatial and semantic coherence between signals [6], which necessitates synchrony and correspondence between displays, controllers and audio devices. Moreover, sensorimotor adaptation follows interactions between physical movements, typically head and hand movements, and corresponding virtual actions. This type of sensory adaptation is vulnerable to spatial and temporal artefacts, particularly when it comes to inertial cues [19].

1.3 Individual differences

Motion sickness and simulator sickness have more than symptoms in common. They both vary in occurrence and severity across individuals. It seems some tolerate virtual sensations better than others, just like some can go from one ride to the next in an amusement park. These individual differences have also been noted for other VR experiences, such as navigation, task performance, and information organisation [17]. Others have touched upon the background of participants and stressed the importance of understanding individual characteristics, ranging from spatial understanding and memory to motor and verbal skills, even gender and personality [4, 11, 17]. Yet we still lack a comprehensive understanding of the characteristics that affect both simulator sickness and usability factors, and how experience and adaptation can serve as mediators [3].

2 DEMONSTRATION SETUP

This demonstration introduces a VR environment with direct control over the motion tracking delay. The environment itself is a simple VR game running on state-of-the-art VR equipment. Participants play single player squash, shown in figure 1, attempting to keep the ball in play. With direct control over delays in the VR scene, participants can experience first-hand the consequences of a fully immersive virtual environment that gradually moves away from a familiar physical law.

2.1 Equipment

The game is developed in the *Unity*[2] game engine using the *Open VR* framework[3]. In terms of content, we present players with a realistic rendering of a squash court. The hand-held controller is displayed in the game as a racket, tracking the user's hand. Using the option for room-scale VR, participants are free to move around the court to hit the ball. Movement of the ball is simulated using approximations of real physics.

For VR display and interactions we use *Vive Pro*[4]. The system used for running the game has yet to be decided, but we will make sure to use hardware that introduces as little delay as possible. With the tested setup[5], this VR game has a an average delay of 38 ms before we add any experimental delay, as measured using the setup described in Raaen and Kjellmo[15].

2.2 Demonstration

The demonstration invites participants to first explore the virtual environment, and the game itself. When they have become acquainted with the game interaction, they have the option to adjust the delay. The selected delay will be introduced between the movement

[1] HTC Vive 19.02.19, https://www.vive.com/us/product/vive-virtual-reality-system/

[2] https://unity3d.com/

[3] https://github.com/ValveSoftware/openvr

[4] https://www.vive.com/eu/product/vive-pro-full-kit/

[5] Intel i9-9900k, 16GB RAM, NVidia GeForce RTX2070

tracking sensor for the headset and the rendered image. Because this is a demonstration rather than an experiment, participants are provided with in-game visual feedback on the extent of the delay. This allows them to explore different settings and how various levels of delay affect their perception and comfort. Participants will be in full control of the extent of the delay through a touch-pad on the controller, as illustrated in figure 2.

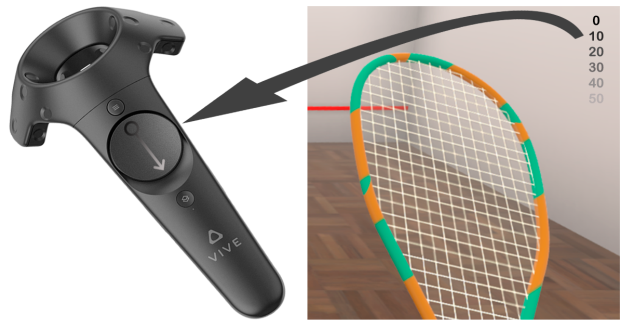

Figure 2: The demo allows participants to control the delay using the touch-pad on the controller, with visual feedback provided in the game.

3 PLANNED EXPERIMENTS

This demonstration introduces a setup that we plan to use in a systematic empirical investigation of the effects of delay in a VR game. In the planned experiments, participants will experience a range of delay levels, without visible feedback on the exact delay affecting them. We will run pilot studies to establish experimental delay levels, taking measures to keep within the boundaries that are unlikely to cause severe sickness. Furthermore, when addressing delay as a variable that affects visuomotor processes, we will need to ensure that all other variables affecting sensory integration are under our control.

We are planning to assess both the short-term and long-term effects that can follow VR interactions. A part of this work will involve a qualitative study on subjective experiences, with the aim to either validate or extend on the popular *Simulator Sickness Questionnaire* [2, 9]. Another aspect involves assessing participants at regular intervals in the 24 hours following the VR experiment, in order to investigate potential long-term effects and their duration. We are also planning to address individual differences that may mediate the subjective experience, including age, gender, VR and game experience, spatial understanding and personality.

4 CONCLUSION

Recent years have seen vast improvements in the processing and rendering capacities of VR systems, leaving fewer issues to understand and fewer challenges to tackle. Nevertheless, the remaining challenges are prominent obstacles to providing users with multisensory, immersive VR experiences free from drawbacks. In order to address these challenges, we must understand how technological limitations manifest as artefacts, how artefacts in turn affect subjective experiences, and how subjective experiences differ across individuals with different characteristics. We propose that this understanding comes from qualitative and quantitative studies with stringent experimental controls, from considering theories on human perception and sensory integration in the experimental design, and from including individual differences as experimental variables.

With this demonstration, we present an interactive VR environment that gives the player the opportunity to manipulate the extent of delay in a game, and experience the immediate short-term effects, along with the potential long-term effects. With the platform, we introduce a tool that gives direct control over this common temporal artefact. Thus, the demonstration serves two purposes. It provides a player platform for first-hand experience of VR delays, and it serves as an experimental platform for future studies on the constraints and consequences of delayed VR interactions.

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